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The NASA New Millennium Program: Flight Validation of New Technologies for 21st Century Science

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THE NASA NEW MILLENNIUM PROGRAM: FLIGHT VALIDATION OF NEW TECHNOLOGIES FOR 21ST CENTURY SCIENCE

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Abstract

A broad range of advanced spacecraft and measurement technologies are needed to support NASA's ambitious plans for space and Earth science observations during the first decade of the 21st century. The New Millennium Program (NMP) supports these efforts by identifying revolutionary technologies and validating them in space to reduce their cost and risk to the first science users. The ongoing NMP missions includes two Deep Space and two Earth Orbiting validation flights. This paper describes the approach used to select technologies for NMP validation missions and summarizes the status of the current and future missions.

1. Introduction

NASA scientists have ambitious plans for space exploration and Earth observations early in the 21st century. These plans include spacecraft targeted to destinations as diverse as the Sun, Jupiter's icy satellite, Europa, and the planet Pluto. Other planetary missions will require highly-autonomous landers, rovers, and sample return vehicles for studies of near-Earth asteroids, comets, and the planet Mars. Advanced astronomical observatories will also be launched to study the structure of the universe and the origin and evolution of galaxies, stars, and solar systems. For Earth science, the first generation Earth Observing System (EOS) platforms will be augmented by smaller EOS and ESSP missions with payloads that are more focused on specific process studies or long-term monitoring objectives. NASA also plans to work closely with the National Oceanic and Atmospheric Administration (NOAA) and other U.S. government agencies to develop the next generation of polar orbiting and geostationary satellites for monitoring the Earth's weather and climate.

A broad range of advanced spacecraft and measurement technologies will be needed to execute these ambitious plans. The New Millennium Program (NMP) supports these efforts by identifying breakthrough spacecraft and measurement technologies and validating them in space. Unlike NASA's other core technology programs, the focus of the NMP is not the development of advanced space technologies. Instead, the NMP compliments these efforts by identifying the products developed under NASA's core technology programs and other programs in the government, industry, and academia, and accelerating the infusion of these technologies into future space missions (Fig. 1). This is not simply a passive harvesting effort, however. The NMP also helps to identify and prioritize the development of breakthrough technologies by playing a leading role in NASA's core technology planning activities.

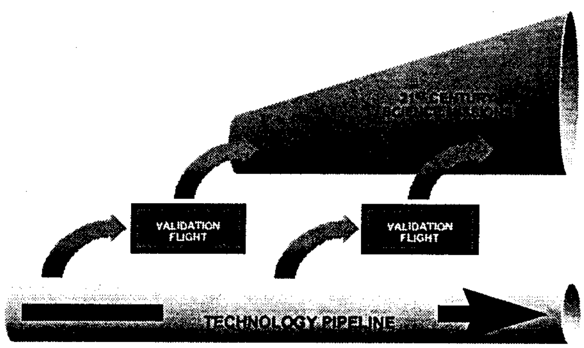

Fig. 1: NMP technology infusion model for 21st century science missions.

The criteria for selecting candidate technologies for NMP flights are summarized below. We then discuss the approach used to select technology suites for specific NMP validation flights, emphasizing the role played by the science, technology, and mission architecture teams in this process. Finally, we summarize the current NMP deep space and Earth orbiting missions.

2. Validation Mission Selection Criteria

NMP validation flights usually include a complementary suite of advanced spacecraft and measurement technologies. Several factors contribute to the choice of these technology suites. To be considered for an NMP validation flight, candidate technologies must satisfy the following 3 criteria. First, they must be essential for achieving high priority science objectives identified in the NASA Office of Space Sciences (OSS) or Earth Science Enterprise (ESE) Strategic Plans. Second, the technologies must represent a breakthrough compared to the current state of the art. Third, a validation in space must be required to reduce the real or perceived risk to the first science users of this technology. These criteria are illustrated in Fig. 2.

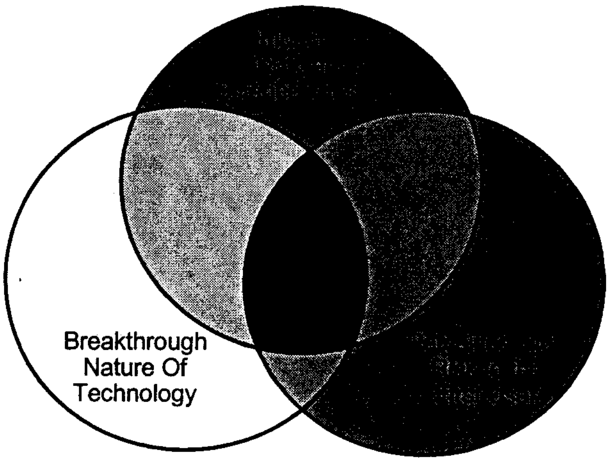

Fig. 2: the Characteristics of NMP technologies.

In addition to the criteria listed above, NMP validation flights are constrained by a number of programmatic factors, including rigorous limits on their total mission cost, flight system development schedule, launch vehicle accommodation, and launch frequency. For example, to maintain a launch rate of one deep space and one Earth-orbiting mission every 18 months, the NMP must interleave small (<30M$) and medium (<100M$) sized validation missions. This aggressive launch schedule is driven primarily by the need to validate new technologies in a timely fashion, such that they are ready for use on high-priority science missions. The launch vehicles for these flights are usually restricted to the Med Lite class or smaller. Partnering options, including shared and piggyback launches are sought for the smaller NMP missions.

Because NMP flights are intended to test new technologies, they are inherently riskier than conventional NASA science missions. Even though a higher level of risk is acceptable for NMP validation flights, risk management is still a high priority. For this reason, and because NMP is a flight validation program rather than a technology development program, the technologies selected for NMP validation flights must have a technology readiness level (TRL) within a specified range. Specifically, technologies selected for NMP flights must have been previously demonstrated in the laboratory environment (NASA TRL 4), but not yet demonstrated in flight (NASA TRL 7 or 8). Technologies at lower TRL's are often too risky to manifest even on a technology validation flight, while those at TRL's exceeding 7 or 8 do not require a flight validation.

Two additional factors contribute to the selection criteria for the technologies included in a specific NMP validation flight. The first is timeliness. If a spacecraft technology is urgently needed for a high-priority science mission that is planned 6 to 10 years in the future, and it meets the criteria listed above, it will have a high priority for the next available NMP flight. However, if it is needed much sooner, it may actually have a lower priority, because it is unlikely that it could be validated in time to contribute to the science mission. If it is not needed until much later, its priority may also be reduced because there is no urgency for its validation

Finally, even though the primary objective of an NMP flight is technology validation, these missions are designed to return science data to the extent possible within the mission design constraints. To address this requirement, NMP missions include advanced scientific instruments as well as other advanced spacecraft technologies. They are also targeted to scientifically-interesting targets to insure that their technology suites are validated in realistic environments. In spite of these features, NMP flights still differ substantially from NASA science missions because their ultimate goal is validate technologies for future science missions, rather than to acquire high priority data from any specific NMP mission.

3. NMP Mission Definition and Selection

NMP missions and technology suites are designed through an interactive process that involves NASA Headquarters (HQ) management, the NMP management, the NASA science and technology communities, and the NMP Architecture design team (ADT). NASA HQ management works with their science advisory committees and the NMP Science Working Group (SWG) to identify high priority science themes that require significant technology infusion. Examples of existing themes include *(i)* spacecraft that provide rapid access to near-Earth Asteroids and comets, *(ii)* coordinated networks of small spacecraft for in-situ studies of planets or their magnetospheres *(iii)* separated-spacecraft interferometers for ultra-high resolution imaging of astronomical objects, *(iv)* autonomous small body rendezvous and sample return vehicles, *(v)* advanced land imaging systems for low Earth orbit, and *(vi)* lidars for measuring winds from space.

Once the theme, schedule, and funding profile for a validation flight have been established, the SWG works with the NMP Integrated Product Development Teams (IPDT's) and Architecture Design Team (ADT) to define one or more mission concepts that addresses the technology validation needs for each theme. In this interaction, the SWG represents the science community and helps to define the long-term science goals that must be enabled by the validation flight.

The IPDT members, who are selected competitively from high-technology industries, the academic community, and government labs, identify candidate advanced spacecraft and measurement technologies that might meet these goals. The ADT then incorporates these technologies validation requirements into candidate mission and spacecraft concepts. The most promising concepts are developed further with the help of a dedicated flight team. This team includes a project manager, a flight scientist, who leads an appointed science definition team (SDT), engineers who specialize in mission design and flight systems, as well as IPDT members familiar with each candidate technology. Once these teams develop the mission concepts to a mature state, they then submitted to NASA HQ for review and approval.

Once a concept has been selected for flight, it enters a formal mission development phase. At that time, the SDT is retired, and a Announcement of Opportunity (AO) or NASA Research Announcement (NRA) is released to solicit the participation of the science community in the flight validation effort. During this phase, the IPDT's work with the flight team and the science team to devise validation and infusion strategies for each new technology. These plans are then implemented once the mission is launched.

4. Ongoing NMP Validation Missions

NASA has approved two Deep Space missions and two Earth Orbiting missions in this program. The first Deep Space mission, DS1, is scheduled to launch in October, 1998. The primary goal of DS1 is to validate solar electric propulsion (SEP) and a suite of 11 other innovative technologies (Figure 3). This mission is targeted to fly past at least one near-Earth asteroid. The SEP technology to be tested on DS1 incorporates a xenon ion propulsion system with advanced solar concentrator arrays. This system is designed to enable rapid access to small bodies that are not readily accessible with standard chemical propulsion. Other technologies to be tested include an onboard autonomous navigation system and other autonomy experiments, a multi-functional structure, and advanced telecommunications and microelectronics systems.

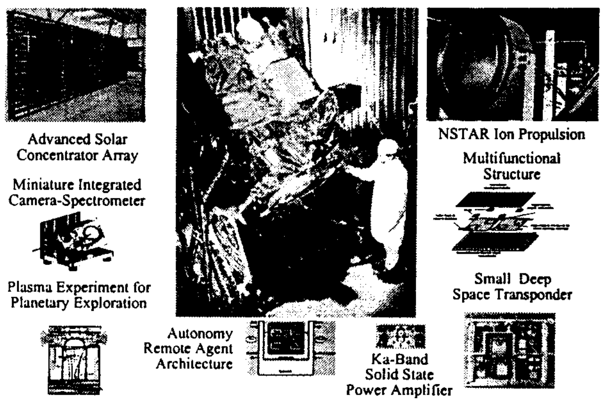

Figure 3: Technologies to be validated by DS1 (illustration provided by the DS1 Flight Team).

DS1 will also validate 2 advanced scientific instruments: the Miniature Integrated Camera Spectrometer (MICAS) and the Plasma Experiment for Planetary Exploration (PEPE). MICAS incorporates a 2-channel visible camera, an ultraviolet imaging spectrometer, and an infrared imaging spectrometer. The wavelength ranges spanned by MICAS are 0.08-0.185, 0.5-1.0 and 1.2-2.4 microns. It will be used for both optical navigation and science observations. PEPE will make in situ measurements of the plasma environment of the target bodies. It is designed to measure electron and ion energies in the range from 3 eV to 30 keV and ion masses from 1 to 135 amu. PEPE will also be used to study the effects of the effluents from the SEP on the spacecraft itself to evaluate the applicability of this important technology to future space science missions.

The DS2 Mission consists of a pair of Mars Microprobes that will be launched in January 1999 as a secondary payload on the Mars Surveyor '98 Lander. They will arrive at Mars on December 3, 1999, landing within 100 km of the Mars Surveyor '98 Lander, which is targeted between 73 and 77° S latitude, and 180° to 210° W longitude. These small, low-cost penetrators will demonstrate a single-stage, passive, atmospheric entry system and a high-impact landing system designed to survive surface impact velocities between 200 and 300 meters per second. On impact, the 18 cm long probe will break through its aeroshell and separate into a forebody and an aftbody, connected by a 2 meter flexible cable (Figure 4).

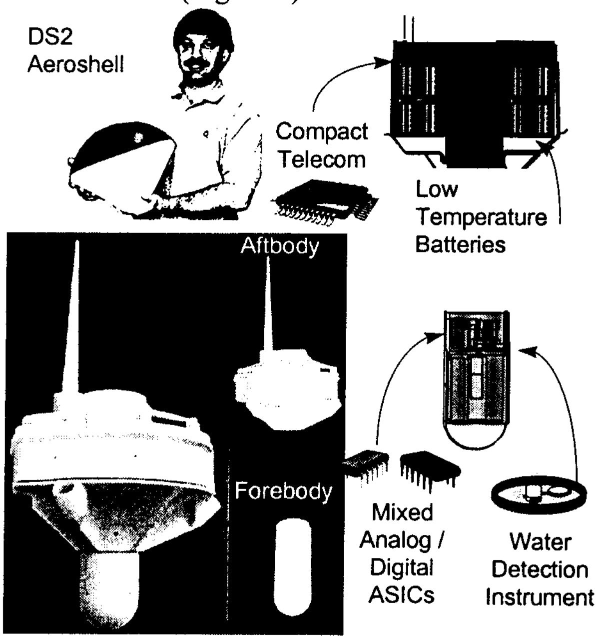

Figure 4: Technologies to be validated on the NMP DS2 Microprobes (images compiled from material supplied by the DS2 flight team).

The forebody delivers a suite of in-situ instruments up to 1 meter below the Martian surface to measure the soil temperatures, heat conductivity, and the water abundance. The aftbody stays on the surface, and carries the probe's batteries, transmitter, a pressure sensor, and a sun sensor. The probes are expected to survive for about 50 hours in the cold (-90° C) Martian polar environment. They will transmit their data back to Earth via the Mars Global Surveyor Orbiter.

The first NMP Earth Orbiting Mission, EO1, is scheduled to launch in 1999. This mission will demonstrate an advanced land imaging system that could lead to substantial cost reductions in future LANDSAT Orbiters. The principle technology on EO1, the Advanced Land Imager (ALI) instrument requires only one seventh the mass, power consumption, and volume as the LANDSAT 7 imager, ETM+. EO1 will also test 2 hyperspectral imaging technologies. To validate these new technologies, EO1 will fly in formation a few minutes behind the LANDSAT 7 satellite, so that the two spacecraft can view the same scenes in similar lighting conditions (Figure 5).

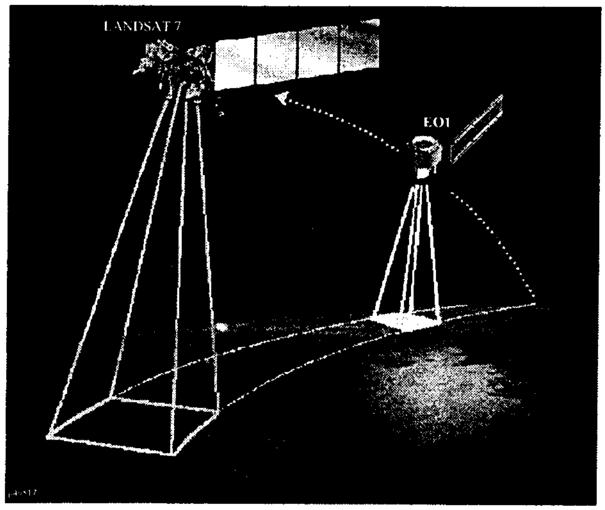

Figure 5: Artist drawing of the EO1 Spacecraft flying in Formation with Landsat 7 (illustration provided by the EO1 Flight team).

The second NMP Earth Orbiter mission, EO2, will provide the first opportunity to validate a space-based wind lidar system. This low-cost mission, called the Space Readiness Coherent Lidar Experiment (SPARCLE) will be carried to orbit as a Hitchhiker payload in Getaway Special (GAS) cans in the Space Shuttle cargo bay. It will employ an eye-safe 100mJ, 6-Hz, 2-micron laser and a coherent detection technique to measure the line of sight Doppler winds at several fixed azimuths (Figure 6). The data collected by this experiment will be used to validate both the lidar system and the numerical models being used to assess the value of wind lidar measurements for global weather prediction models. The EO2 launch is tentatively scheduled for early 2001 (pending assignment to a specific Space Shuttle flight).

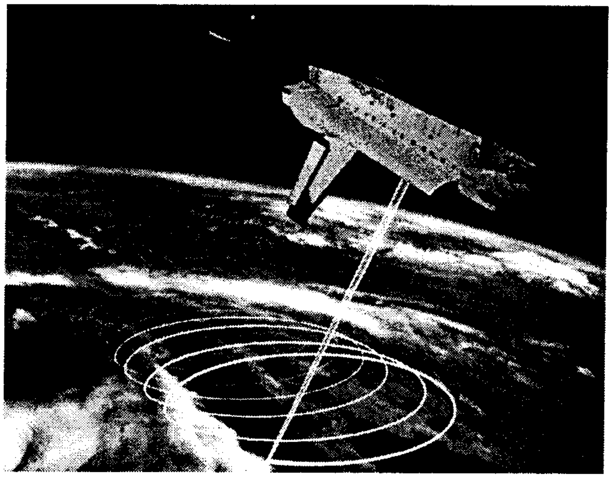

Figure 6: The EO2 Space Readiness Coherent Lidar Experiment (SPARCLE) validating Doppler wind measurements from the Space Shuttle (Illustration provided by the SPARCLE Flight Team).

5. Future NMP Validation Missions

Two additional Deep Space Missions are currently seeking approval as NMP validation flights. The first is a separated spacecraft optical interferometer (DS3). In its current configuration, the interferometer employs 3 spacecraft flying in formation at distances between 100m and 1 km (Figure 7). The two smaller spacecraft collect light from astronomical objects with small (12 cm) mirrors, and direct the light to a beam combiner in the third spacecraft. Laser metrology and a Kilometric Optical Gyro (KOG) will be used to monitor and maintain the spacecraft formation. Two-dimensional aperture synthesis is then used to form an image of the object, yielding spatial resolutions that greatly exceed those attainable with conventional, single-aperture telescopes (0.1 to 1 milli-arc-second).

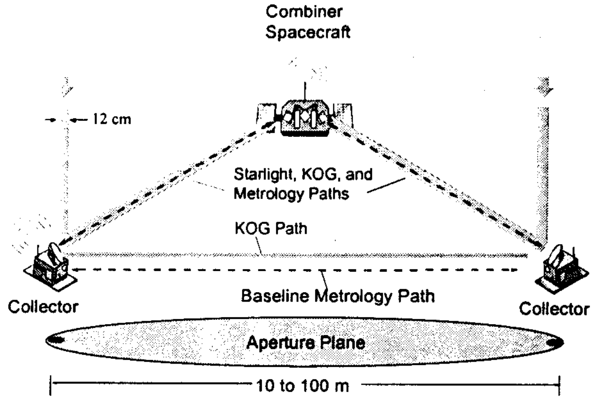

Figure 7: Nominal configuration of the NMP DS3 separated spacecraft interferometer, showing the collector and combiner spacecraft, the starlight paths, the laser metrology paths, and the Kilometric Optical Gyro (KOG) paths.

Because the relative positions of the collector and combiner spacecraft must be monitored and controlled very precisely, several advanced technologies will be validated, including lasers and other position-measuring technologies, pulse plasma thrusters for spacecraft translation and attitude control, coordinated precision, autonomous formation flying algorithms, and advanced avionics. If approved, this mission will be launched into a heliocentric orbit in 2002, and operate for approximately 6 months.

The second deep space mission that is now under consideration will rendezvous and land on comet. If all goes as planned, this mission will be launched in 2003. About 2.5 years later, it will rendezvous with periodic Comet Temple 1 as it moves away from the sun after its latest perihelion passage. Because this mission carries the Champollion science instruments as well as a suite of advanced technologies, it has been designated DS4/Champollion. After spending a few months studying the comet with remote sensing instruments, the 100 kg Champollion lander will be sent to land on the comet nucleus. The lander will first anchor itself securely to the comet. It will then take high-resolution images of the surrounding terrain, close-up images of the surface, and drill up to one meter deep into the nucleus to collect samples of cometary ices and dust. These samples will be studied by a microscopes, an infrared spectrometer, and a gas chromatograph/ mass spectrometer on the Lander, and the results will be radioed back to Earth. The lander will also collect samples in a specially designed canister for return to the carrier spacecraft (Figure 8).

Figure 8: An artist's drawing of the NMP DS4/Champollion lander leaving the surface of the comet and returning to the carrier spacecraft (illustration from the DS4/Champollion Project).

This mission will validate a host of new technologies needed specifically by future missions to comets and other small bodies, including autonomous rendezvous, landing, sample acquisition, and sample transfer. It will also demonstrate an advanced, high-performance SEP system that uses multiple engines and an advanced, lightweight, solar array (100 W/kg) that is deployed by inflatable supports and then rigidized. An advanced, cryogenically-controlled sample return vehicle is also under consideration for this validation flight. If this vehicle is included, the DS4/ Champollion mission will return a sample to the Earth in 2010.

6. Conclusions

Even though the first launch of an NMP mission is still several months in the future, we have recently started to discuss options for DS5 and EO3. Plausible candidate mission suites should be available within one year. Also, in spite of the short time that his program has been operating, it has already had a profound effect on NASA's future space and Earth science missions by identifying high-risk, high-payoff technologies, and showing that they can be integrated into state-of-the-art spacecraft on a short schedule at a modest cost. The confidence that these system-level, pre-launch validation efforts has generated can be measured by the large number NMP technologies that have been adopted by Principle Investigators in the NASA Discovery, SMEX, and ESSP programs even before they have been validated in space.

In spite of this progress, the NMP, like any high technology program, includes inherent risks that cannot always be anticipated. In fact, if we are entirely successful in this first few NMP flights, one could argue that we are being too conservative. In addition, numerous opportunities to improve the processes used for mission and technology selection, and technology infusion have been identified as the first NMP spacecraft were being prepared for launch. We have therefore initiated a comprehensive review of our processes, to insure that they are more fair, open, competitive. It is our hope that these new processes will provide a model for infusing technologies into future high-technology space missions.

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